TABLE II.—Showing the Electromotive Properties of Muscle-cylinders cut from the Eight Muscles in Table I.

Muscle.	Distance of lower cut surface from tendon.	Length of cylinder.	Distance of point F from lower cut surface.	Potentials of undermentioned points compared with F=0·0.		
				Most positive point of natural surface.	Most negative point of natural surface.	Centre of lower cut surface.
Frog 1:						
Gastr. *r*	1·6	2·0	0·5	+4·0	−2·5	−5·7
" *l*	1·2	1·7	0·8	+4·5	0·0	−3·3
Frog 2:						
Gastr. *r*	1·4	1·5	0·85	+2·6	−3·4	−4·8
" *l*	1·6	1·4	0·0	+2·5	−1·0	−3·4
Frog 3:						
Gastr. *r*	1·5	1·5	0·8	+0·8	−4·1	−4·8
" *l*	1·2	1·4	0·6	+1·8	−1·5	−4·0
Frog 4:						
Gastr. *r*	1·2	1·6	0·0	+1·4	0·0	−2·9
" *l*	1·2	1·6	0·0	+0·0	0·0	−2·9

III. "Preliminary Notice of Investigations on the Action of the Vaso-motor Nerves of Striated Muscle." By W. H. GASKELL, M.A., Trinity College, Cambridge. Communicated by Dr. MICHAEL FOSTER, F.R.S. Received November 23, 1876.

(Abstract.)

When a muscle is thrown into a state of tetanus by stimulation of its nerve, it seems, at first sight, reasonable to suppose that the contraction of the muscle substance must cause a considerable pressure on the vessels of the muscle, and, therefore, that for this reason less blood must pass through; and, if at the same time that the motor fibres are stimulated vaso-constrictor fibres are also stimulated, one must conclude that during the tetanus of a muscle there is a very much less volume of blood flowing through.

On the other hand, in order for the muscle to do work for any length of time, it is necessary that there should be a greater facility for the removal of the waste products and a more active supply of nutritive material during the state of contraction than when the muscle is at rest. This hypothesis necessitates, therefore, a greater flow of blood through the muscle during the tetanus of that muscle.

Which of these two statements is the true one, Sadler (Ludwig's 'Arbeiten,' 1869) has already indicated. As, however, his method and his results are not absolutely satisfactory, I, at the suggestion and with the help of Professor Ludwig, carried out last year, in Leipzig, a series of experiments of the same nature as his, and, by means of much improved

apparatus, was enabled to obtain much more satisfactory and trustworthy results than he did.

Speaking briefly, we found that, in the case of the quadriceps extensor of the dog, stimulation of the anterior crural nerve, by means of the interrupted current for a short time, say 15 seconds, caused a considerable outspurt of blood from the muscle-vein, followed by a complete cessation of flow, and that at the end of the tetanus there was an immense outpouring from the vein.

In the case of a longer tetanus we saw that, following upon the temporary cessation of flow, blood again began to stream out, gradually and continuously increasing in volume, until at last, even while the muscle was still in a state of tetanus, there was much more blood flowing from the vein than before the commencement of the stimulation.

On my return to England, wishing to examine more closely this phenomenon, I determined to investigate it, if possible, under the microscope in the muscles of the frog; and rejecting the tongue, for reasons stated below, I found that the mylohyoid muscle was the most suitable one for my purpose, it being easy to prepare it for microscopic observation without damaging the circulation through it, and, in fact, without even touching the muscle; whilst, owing to its thinness, the small amount of connective tissue in the neighbourhood of the vessels, and the absence of pigment-cells, it is possible here to measure with a micrometer eyepiece the diameter of vessels more accurately and easily than in any other preparation.

Upon placing this muscle under the microscope, without having previously touched the nerve, it is seen that the circulation presents much the same character as in the web, the median red-corpuscle stream with an inert layer on each side being plainly visible, although, perhaps owing to the manipulation, the arteries at first are slightly fuller and more dilated than the corresponding vessels in the web. The calibre of the smaller arteries does not, as a rule, remain for any length of time the same, variations taking place somewhat similar to what has often been described in the vessels of the web, but with this difference, that whereas in the so-called "rhythmic contractions" of the arteries in the web the artery appears to contract to a certain point and then to return to its original calibre or beyond it, in the arteries of the muscle the vessel appears to dilate from the normal calibre, and then gradually to return to that calibre or below it. These dilatations vary considerably in extent and are absolutely irregular in time, being much less marked both in frequency and extent in some frogs than in others, and depend, so it seems to me, probably upon some chance stimulation of the vessels, such as exposure to the air, &c.

Upon direct stimulation of the web by means of the interrupted current there occurs a most marked constriction, not only of the arteries between the electrodes, but extending over the whole web, both during

the stimulation and for some little time after the stimulation is over. If, however, the electrodes are applied directly to this muscle, even to that part which is furthest removed from the point of entrance of the nerve, it is possible, by careful focusing, to see that even during the tetanus of the muscle, provided that that tetanus is slight, instead of a diminished flow, instead of a marked constriction of the arteries throughout the muscle, there is, not only after the stimulation has ceased, but even during the tetanus itself, a most marked increase in the fullness of the vessels, a much greater rapidity of stream, and a very considerable dilatation of the smaller arteries, even to a larger extent than the doubling of the diameter; and if at the same time the circulation through the muscle is very languid, the arteries constricted, and many of the capillaries empty, a slight stimulation of the muscle itself is all that is necessary to cause a rapid full flow through the whole muscle. Whether the arteries immediately between the electrodes contract, I cannot yet say; I can, however, affirm positively that there is no contraction of the smaller arteries situated but a slight distance from the electrodes, or if there is, it must take place in the very short space of time necessary for refocusing on the artery under observation, as in every case, as soon as I have been able to measure the calibre again, I have found it considerably dilated. Here, then, is a marked difference between the web and mylohyoid on direct stimulation.

As to the effect of section of the nerve, I have always noticed that it is followed by a decided reddening of the corresponding muscle, the difference of colour being manifest, as previous to the section the two mylohyoid muscles are always equally pale. Upon closer examination, by first putting the muscle in position under the microscope and then cutting the nerve, it is seen that about 5 to 6 seconds after section the arteries dilate very rapidly, the dilatation soon reaching a maximum, in perhaps 20 or 30 seconds, and then gradually diminishing until the original calibre is reached, some 4 or 5 minutes after section—that is, the dilatation caused by section of the nerve is not a lasting one, but is exceedingly similar to that caused by slight mechanical stimulation of the nerve; for whether its peripheral extremity is pinched by a pair of forceps, or dipped into concentrated salt solution, or still more markedly when cut and torn by scissors and forceps, there always occurs after a brief latent period of a few seconds, during which there is no trace of constriction, a considerable rapid dilatation of the artery, which lasts but a short time, and then gradually gives way to a return to the original calibre, and is always accompanied by a more active very full stream, the inert layer having wholly disappeared, and the red corpuscles being crowded together to the very edge of the vessel. Here, then, is another marked difference between the web and the muscle.

If the peripheral end of the nerve is stimulated with a fairly strong interrupted current, so slight a dose of curare having previously been

given as thereby to cause a decided tetanus of the muscle, it is possible to observe, under a low power of the microscope, similar phenomena to those that take place in the experiments on the blood-stream in the quadriceps extensor of dogs that I have already referred to. Upon the commencement of the tetanus there is a sudden onward propulsion of the blood in the large veins, followed by a complete stoppage of the blood-stream in them, even sometimes a retrograde stream; while in the arteries the stream flows steadily on, increasing in rapidity and increasing in fullness; the arteries dilate, the capillaries on the arterial side become large, filled with blood, very active, and, finally, after a few spasmodic attempts to move onwards, the blood in the veins seems to burst the restraining barriers, moves on more and more rapidly, continually increasing in fullness, even though there is still a steady tetanus of the muscle; and at last, on ending the stimulation, there is seen an extremely rapid, greatly dilated circulation throughout the whole muscle; gradually and slowly the stream slackens, the arteries contract, and at last there is again a quiet axial stream in the arteries and a slow steady flow in the veins. At the moment of commencing and ending the stimulation there is an instantaneous stop in the arterial flow; except at these times, the blood flows continuously in the arteries during the whole stimulation. This phenomenon confirms in every particular the observations made by me at Leipzig, and explains most satisfactorily the nature of the curves obtained there.

By employing larger doses of curare it is possible to examine the effects of nerve stimulation apart from all contraction of the muscle. The following facts are observed then, in a thoroughly curarized muscle, upon stimulation of the nerve by means of an interrupted current. Whether the stimulus is long or short, there is always a rapid and very marked dilatation of the artery under examination, which does not commence until some 5 or 6 seconds after the beginning of the stimulation. During this latent period there is not the slightest trace of any constriction, the calibre of the vessel remaining either the same as before the stimulation, or if the stimulation is applied while the artery is dilating or constricting, then this dilatation or constriction continues during this period; and even if the stimulation is applied at a time when the artery is considerably dilated, there is no trace of constriction, but, on the contrary, a still further dilatation. The maximum of dilatation occurs about 20 or 30 seconds after the commencement of the stimulation, and can be so great that the diameter of the artery may attain to nearly three times that which it possessed originally; it is always accompanied by a greater rapidity and fullness of the blood-flow, the whole circulation throughout the muscle becoming much more active; it lasts, as a rule, only a few seconds at this maximum height, and then the size of the vessel gradually diminishes to the normal, the blood-stream becoming thinner and rather slower, until, as before the stimulation, there is a steady normal axial

flow. It is not possible to keep up the dilatation for any length of time, so that if the stimulation is long, say a minute or more, before the end of it the vessel may have regained its normal calibre; and if the stimulus is long enongh and strong enough, then it is possible for a secondary effect to be produced in the form of a decided constriction of the vessel following upon the dilatation and occurring after the stimulation is ended, this, again, being followed by a recovery to the normal diameter. It is thus seen that, while in the case of the web stimulation of the sciatic always causes constriction, followed after strong stimulation by dilatation, in the case of the muscle stimulation of its nerve always causes a dilatation of the vessels, followed, after strong stimulation, by a decided constriction of the same; so that it seems highly probable that, when the sciatic in the frog is stimulated, constriction in the web is accompanied by dilatation in the muscles of the leg, and dilatation in the web by constriction in those muscles. Moreover, as it is possible to keep up the constriction in the web for a much longer time, by commencing with a weak stimulus and gradually increasing its strength, so I think, too, that the dilatation in the muscle can be made more enduring by the same method.

Rhythmic stimulation of the nerve, by means of single induction-shocks, repeated at intervals of 2 or 5 seconds, produces the same kind of dilatation as the interrupted current.

If, as sometimes occurs, owing perhaps to the muscle being overstretched or some other cause, the circulation through it is found to be nearly stagnant, the arteries constricted, the capillaries barely visible, it is only necessary to stimulate the nerve in order to produce a full active circulation throughout; and this occurs even during the stimulation; while, under the same circumstances, in the web there is still further stagnation produced, still greater constriction, and it is only after the stimulation has ceased that an increased and more active flow takes place.

A marked dilatation of the vessel is often seen to occur in an apparently empty artery before the first rush of blood-corpuscles makes its appearance; and this dilatation does not always occur over the whole vessel at once, but rather parts of the previously constricted vessel appear to bulge out, the intermediate parts remaining still constricted; so that the vessel has somewhat the appearance of a string of pearls, and gradually as the vessel dilates more and more, and the blood-stream increases in volume and rapidity, the walls of the vessel lose this uneven appearance and become uniformly dilated.

Seeing, then, that even when the blood-current in the muscle is feeble (that is, when the pressure in the vessel is diminished) stimulation of the nerve always causes a marked dilatation, I determined to observe the effect of stimulation when the arterial pressure had been removed by compressing the aorta.

Directly after the aorta is compressed by a clip a steady, rather rapid con-

striction of the artery takes place, which soon reaches its limit, and the hitherto slowly moving corpuscles remain stationary, the vessel appearing empty, except for a few corpuscles stationed here and there. Upon now stimulating the nerve the vessel is seen steadily to dilate, a slow stream of corpuscles appears in it moving in the reverse direction (that is, from the veins to the artery), and this occurs without the slightest trace of muscular contraction. The dilatation is very appreciable, though not, so far as I have seen, of as great an extent as the stimulus produces when there is a normal blood-stream in the vessel; and if now the aorta is unclipped, there is at first a slight constriction, followed by a much greater dilatation.

At present it appears to me that the pressure in the vein is sufficient to account for this phenomenon; I intend, however, to carry out further experiments on this point.

As to reflex stimulation, I have never been able to cause any dilatation in the arteries of the mylohyoid by stimulation of the central ends of either the sciatic or vagus nerves; but, on the contrary, I have always seen either no effect produced, or a decided though slight constriction of the vessel—slight, that is, in comparison to the marked constriction occurring in the arteries of the web under the same circumstances.

Lovén having noticed the occurrence of dilatation in the saphena artery and in the vessels of the ear of the rabbit upon stimulation of the central end of the tibial nerve and the great auricular respectively, I have attempted to obtain similar dilatation in the web by stimulating the central ends of either the peroneal or posterior tibial nerves, the other nerve in each case being left intact, and, in the mylohyoid and pectoralis major muscles, by stimulation of the central end of the opposite mylohyoid and brachial nerves respectively, but in each case have seen no trace of dilatation, but always constriction.

As to the effect of direct stimulation of the spinal cord upon the vessels of a muscle, I think it probable that dilatation occurs, as Hafiz has asserted; but as I have not yet made any systematic experiments to determine this point, I think it best to leave this question for future consideration.

Atropin does not impair the action of the nerve on the vessels of the mylohyoid; for after repeated injections of sulphate of atropin subcutaneously, until, with very strong stimulation of the vagus, no effect could be produced on the heart, it was still easy to cause dilatation of the arteries in the muscle by stimulation of the nerve. So, too, large and repeated doses of curare produce no such effect here, as they are said to do on the vagus fibres in the heart.

As Claude Bernard has described a dilatation of branches of the facial artery and an increase of secretion in the submaxillary gland upon stimulation of the mylohyoid nerve in dogs, I have examined other muscles in the frog, and have found that the same phenomena can be produced in

the lateral portion of the rectus abdominis muscle and the abdominal portion of the pectoralis major muscle.

As to the tongue, it seemed to me that having here a more complicated organ, supplied with so many more nerves than a simple muscle, and one that had been already frequently examined without much success, it was not so suitable to the object in view. From the few experiments, however, that I have made on this organ, it seems to me that stimulation of the glossopharyngeal nerve, rather than the hypoglossal, causes dilatation of its vessels.

In concluding this short sketch of my experiments I would venture to say that as, from my own observations, stimulation of the anterior crural nerve of dogs causes dilatation of the vessels in that group of muscles known by the name of quadriceps extensor, while Sadler has shown the same for the biceps and semitendinosus muscles and for the flexor communis digitorum of the forearm, and as, in frogs, stimulation of their respective nerves causes dilatation of the vessels in the mylohyoid, pectoralis major, and rectus abdominis muscles, it is reasonable to suppose that this holds good for simple voluntary muscles throughout the body.

I would further add that the beauty of the circulation and the extent of the dilatation that may be observed in the arteries of the mylohyoid muscle lead one to hope that further investigations here may materially assist in solving the vexed question, "What is the mechanism by which dilatation of a vessel is caused?"

All the foregoing observations on the circulation in the muscles of the frog were carried on in the Physiological Laboratory of the University of Cambridge.

IV. "Note on the Photographic Spectra of Stars." By William Huggins, D.C.L., LL.D., F.R.S. Received December 6, 1876.

In the year 1863 Dr. Miller and myself obtained the photograph of the spectrum of Sirius.

"On the 27th January, 1863, and on the 3rd March of the same year, when the spectrum of this star (Sirius) was caused to fall upon a sensitive collodion surface, an intense spectrum of the more refrangible part was obtained. From want of accurate adjustment of the focus, or from the motion of the star not being exactly compensated by the clock movement, or from atmospheric tremor, the spectrum, though tolerably defined at the edges, presented no indications of lines. Our other investigations have hitherto prevented us from continuing these experiments further; but we have not abandoned our intention of pursuing them" *.

I have recently resumed these experiments by the aid of the 18-inch

* Phil. Trans. 1864, p. 428.